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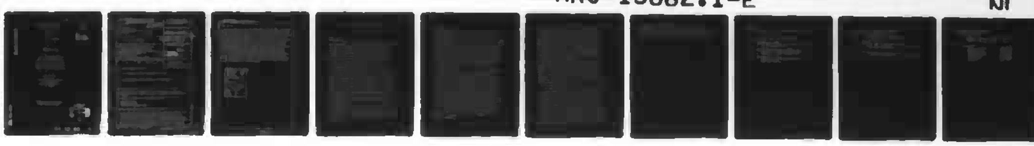

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A STUDY OF THE MECHANISM OF LEAN LIMIT FLAMMABILITY

FINAL REPORT

by

Roger A. Strehlow

August 31, 1981

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The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

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FLAMMABILITY LIMIT
EXTINCTION OF PREMIXED FLAMES

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In this study the mechanism of extinction of a lean limit flame in a premixed methane-air or propane-air system was studied in a vertical rectangular flammability tube with variable inside dimensions. Both upward and downward extinction were observed for methane while only upward extinction was studied for propane. In addition to the observations of extinction, a theoretical analysis of the flow ahead of the upward propagating flame was made which showed that at extinction the upward

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propagating flame is severely stretched in the Karlovitz sense. The upward propagating flame in the 50 x 50 mm tube had a stable hemispherical shape with a trailing skirt towards the walls. Extinction in this case occurred from the central holding region of the flame where the stretch was calculated to be the maximum. In larger than 50 x 50 mm tubes the flame is hydrodynamically unstable and extinction occurs on one of the instability cycles. The downward propagating flame in methane is almost flat in the tube but it propagates in an unstable manner. It was observed, both with image intensifier photographs and with a schlieren optics, that this flame extinguished by first losing heat to the walls. This yielded a small flame in the center which was still propagating downward. At this point in time the cooler gases at the walls were driven downward more rapidly than the flame by differential buoyancy of the product gases and the small flame in the center found itself surrounded by combustion products. This led to final extinction. Thus the downward propagating flame is extinguished by heat loss mechanism coupled with a differential buoyancy driving mechanism which is sufficiently complex that it cannot be modeled using one dimensional heat loss theories.

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A STUDY OF THE MECHANISM OF LEAN LIMIT FLAMMABILITY

by

Roger A. Strehlow

Problem Studied:

The problem that was studied under this grant and contract is the lean limit flammability behavior of methane-air and propane-air systems. Attention was focused primarily on the mechanism by which the flame extinguishes in a particular apparatus or geometry. At the start of the study the upward propagating flame in a square or rectangular flammability tube was chosen for study. In this geometry the flame is quasi steady in coordinates that move up the tube at the speed that the flame moves up the tube. Thus, this is by far the simplest system that one can handle either numerically or analytically.

An apparatus was constructed that allowed us to look at flame propagation in tubes that ranged from 20 mm x 20 mm in section up to 200 mm x 200 mm in section. This system was so designed that any combination of 20, 50, 100 or 200 mm cross sections in either direction could be made easily. Two opposing walls of the tube were glass and the tube was 1.2 m long. It was mounted vertically in a schlieren beam on a rack that allowed any portion of the tube to be viewed by the 12 inch diameter schlieren system. Additionally, heat transfer to the wall was measured using a sensitive heat transfer gage and the flame was photographed during normal propagation and extinguishment using an image intensifier camera.

While the primary thrust of the study was on upward propagating flames in a methane-air system, downward propagation extinguishment was studied in methane-air and upward propagation extinguishment was studied in a propane-air system.

It had been observed previously that the flow ahead of the flame in an upward propagating situation was essentially a potential flow not influenced by viscous interactions with the wall. Therefore, a numerical and later an analytical technique was developed to determine the amount of flame stretch that existed in an upward propagating flame at the time of extinguishment.

Major Results:

The most important result of this study is the identification of the mechanism for lean limit extinction for both an upward and downward propagating flame. In the case of the upward propagating flame at the time of extinction, a hole develops in the center of the flame and propagates downward to the skirt of the flame until the flame is completely extinguished. Theoretically, we have shown that in this upward propagating near limit flame, the flame stretch due to the curvature of the flame in the flow is maximum at the center line and we know that this is also the holding region for the propagating flame. Thus, the upward propagating flame in a 50 mm tube evidently extinguishes by a stretch mechanism. Heat loss to the walls is not important in this case. We have proved this by noting that heat loss to the walls does not occur until the skirt touches the wall and this is quite far removed from the point where extinguishment first occurs.

In the downward propagating flame, the mechanism is quite different. Here, the flame consists of a number of uneven sections propagating at variable rates down the tube. The flame is highly unstable in this configuration. Image intensifier photography as well as schlieren photography has shown us that this flame extinguishes by a mechanism which involves first the extinguishment of the flame near the wall due to heat loss to the wall. After that happens, the gases near the wall become colder than the combustion gases following the central downward propagating flame and differential buoyancy drives the gases that are near the wall downward and the gases behind the flame upward. At the moment of final extinction, we observed that the small central downward propagating flame actually traveling up the tube at a very low velocity, becoming more and more surrounded by the combustion products that are near the wall. Therefore, this mechanism is one of heat transfer to the wall coupled with a buoyancy driven instability which terminates the flame. Note that even though this extinguishment is driven by a heat transfer mechanism, it is not one dimensional nor could it be modeled in one dimension.

Another major conclusion that has been arrived at as a result of these studies is the inference that the extinction mechanism is never a one-dimensional mechanism. The stretch mechanism is two dimensional and the buoyancy mechanism is 3-dimensional nonsteady. Another piece of information which supports this view is the fact that one dimensional non-steady numerical codes are used to calculate burning velocity and flame structure. These codes can and have been used to calculate burning velocity and flame structure for flames well beyond the limit flames that are observed in the laboratory. If a one-dimensional mechanism were predominate in the extinction process, one would expect that one would not be able to calculate the structure of a 2% methane flame using a one-dimensional nonsteady code when the normal limit is 5% methane. Yet, this is done without any difficulty.

As a result of this study, we have also observed that upward propagating flames in tubes that are larger than 50 mm show signs of instability. It is apparent here that the tubes with larger dimensions have a flame with less stretch. Thus it appears that positive stretch caused by flow restrictions can stabilize a flame against cellular instability. It is interesting to note that the propane flames that we studied also exhibited the same type of cellular instability in large tubes even though on the lean side they should be cellularly stable. The reason for this has not been resolved.

As a result of our observations it can be postulated that the lean limit upward propagating flame is actually an overdriven flame when it is ignited and then slowly relaxes either to a normal propagating flame some distance from the ignition source or relaxes to extinction. There are a number of observations that support this comment. The primary one is the fact that when hand held matches are used to ignite the flame it is extremely difficult to get the flame to extinguish in the middle portion of the tube on a regular basis. A hand held match is, of course, an ignitor which is highly variable from run to run. However, when a heated electric wire was used as the ignitor, it was much easier to get extinguishment in the neighborhood in the central portion of the tube. Since the electrically heated wire is more reproducible from run to run, it appears that we are actually overdriving the flame initially and it is then relaxing to its final state of either propagation or extinction. Based on these observations it would be very interesting to propagate a lean limit flame across a diffusion boundary such that second gas mixture is either outside the normal flammability range or just inside the normal flammability range. The time to relax to the new conditions would be an interesting measure of the forces driving the extinction process.

Publications:

This Grant-Contract has led to the following completed theses:

Ph.D. Ernst von Lavante (1980)
The Mechanism of Lean Limit Flame Extinction

M.S. Bernard P. Paul (1980)
The Thermal Structure of Lean Limit Flames in a Variable Geometry Flammability Tube

M.S. Robert Rexford Chamberlain, Jr. (1980)
Analysis of Gas Samples Taken from a Methane-Air Flame Propagating in a Square Flammability Tube

M.S. Ali Gilday Gumas (1981)
Extinction Behavior of Upward Propagating Lean Limit Propane-Air Flames

Papers submitted or in preparation for publication:

E. von Lavante and R. Strehlow
The Mechanism of Lean Limit Flame Extinction
(submitted Combustion and Flame)

R. Strehlow and A. Azarbarzin
Visible Light Photography of Flame Extinction in a Vertical Flammability Tube
(in preparation) to be submitted to Combustion and Flame

R. Strehlow and A. Gumas
Lean Limit Flame Extinction in a Flammability Tube
(in preparation) to be submitted to Combustion and Flame

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von Lavante, Ernst	Ph.D. degree
Paul, Bernard P.	M.S. degree
Malik, Sarmad	Grad student
Gumas, Ali	M.S. degree